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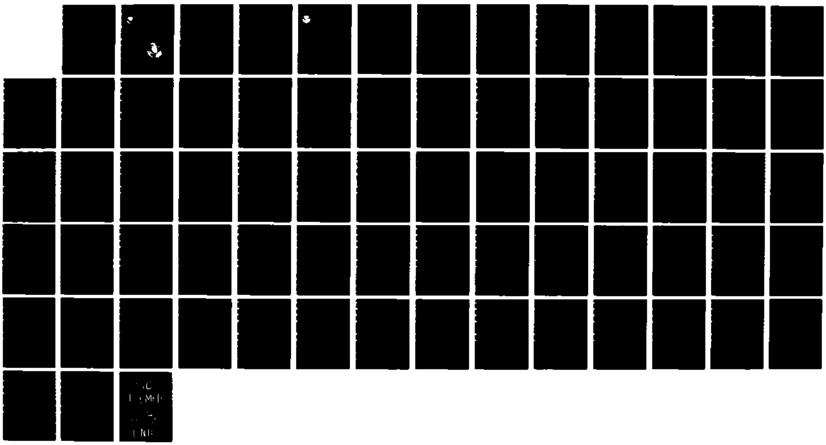

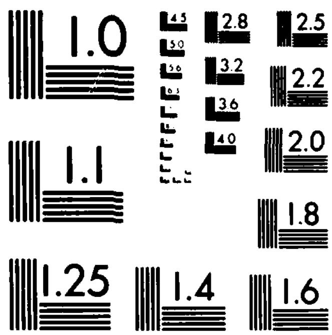

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ENVIROSAT—2000 Report

Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000

VOLUME 1

April 1985

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

UNCLASSIFIED, UNLIMITED

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Based on the experience of the past 15 years, we established the best management principles to apply to the POES for the next 15 years. We did this for both a two-satellite configuration and a one-satellite configuration. The principles include always having a spare available, a 4-month call-up capability, taking advantage of satellites that live longer than their design life, and taking advantage of early indications of imminent failure. These principles must be applied in different ways to the two configurations.

Applying these principles to several scenarios for the future leads to the conclusion that we should plan for 12 satellites

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Volume I is an independent document, covering the purpose and methods of the analysis and reporting its conclusions. A discussion of the analysis process is provided. Sample data sets and summaries of case study results are included. Conclusions are developed in this volume.

Volume II presents a complete description of the analysis approach. Data collection and data compilation methods are explained and the procedures for comparing and evaluating case studies are examined. Figures and tables are used to illustrate findings.

Volume III provides the time-series graphical representations of the 121 satellite deployment and failure scenarios that were the case studies of the analysis. The statistics and other tabulations that were used in the analysis are included.

ENVIROSAT—2000 Report

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VOLUME 1

W.H. Eskite, Jr., and W.P. Bishop

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April 1985

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U.S. DEPARTMENT OF COMMERCE
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National Environmental Satellite, Data, and Information Service
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OPTIMUM MANAGEMENT STRATEGIES FOR THE NOAA POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITES; 1985 TO 2000

ABSTRACT

Based on the experience of the past 15 years, we established the best management principles to apply to the POES for the next 15 years. We did this for both a two-satellite configuration and a one-satellite configuration. The principles include always having a spare available, a 4-month call-up capability, taking advantage of satellites that live longer than their design life, and taking advantage of early indications of imminent failure. These principles must be applied in different ways to the two configurations.

Applying these principles to several scenarios for the future leads to the conclusion that we should plan for 12 satellites for the next 15 years for either the one-satellite or the two-satellite system.

PREFACE

This report, Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985 to 2000, is published in three volumes.

Volume I is an independent document, covering the purpose and methods of the analysis and reporting its conclusions. A discussion of the analysis process is provided. Sample data sets and summaries of case study results are included. Conclusions are developed in this volume.

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TABLE OF CONTENTS

VOLUME 1

INDEX TO FIGURES

INDEX TO TABLES

EXECUTIVE SUMMARY CHARTS

The following briefing charts provide a concise overview of the goals, analyses, and findings of this study.

GOALS OF THE STUDY

TO DEFINE THE OPTIMUM STRATEGIES FOR MANAGING THE POES

- IN A ONE-SATELLITE CONFIGURATION
- IN A TWO-SATELLITE CONFIGURATION
- OPTIMUM IS BEST SERVICE AT LOWEST COST

TO DETERMINE HOW MANY SATELLITES SHOULD BE PROCURED FOR THE REST OF THE DECADE

- FOR A ONE-SATELLITE SYSTEM
- FOR A TWO-SATELLITE SYSTEM

SERVICE GOALS FOR THE POES

MINIMUM SERVICE GOAL IS ONE SATELLITE AT ALL TIMES

- SOUNDINGS
- IMAGERY

SOME DEGRADATION FOR BRIEF PERIODS IS ACCEPTABLE, BUT NOT COMPLETE LOSS OF SERVICE, I.E., THE MORNING ORBIT IS ACCEPTABLE FOR BRIEF PERIODS

ADDITIONAL DATA (I.E., FROM TWO SATELLITES IN DIFFERENT ORBITS) HAS CLEAR BENEFITS AND IS DESIRABLE

STATISTICAL BASIS FROM PAST PERFORMANCE

THREE LAUNCH FAILURES OVER 15 YEARS

TWO SATELLITES FAILED TO REACH THEIR DESIGN LIFE

- 9 MONTHS (12-MONTH DESIGN)
- 15 MONTHS (24-MONTH DESIGN)

EIGHT EXCEEDED THEIR DESIGN LIFETIMES

- 17 MONTHS (12-MONTH DESIGN)
- 28 MONTHS (12-MONTH DESIGN)
- 34 MONTHS (12-MONTH DESIGN)
- 49 MONTHS (12-MONTH DESIGN)
- 37 MONTHS (12-MONTH DESIGN)
- 30 MONTHS (14-MONTH DESIGN)
- 52 (OR 66) MONTHS (24-MONTH DESIGN)
- 42 MONTHS AND STILL OPERATING (24-MONTH DESIGN)

THESE SET RANGES OF LIFETIMES AND NUMBERS OF FAILURE EVENTS (LAUNCH AND SHORT LIFE)

History of the
Polar-Orbiting Operational Environmental Satellite System
since 1970

```
------------------------------------------------------------------------------
| Satellite|                            Years                                 |
|----------------------------------------------------------------------------|
|          |  1970  |  1971  |  1972  |  1973  |  1974  |  1975  |  1976  |  1977  |
|----------------------------------------------------------------------------|
|      1/23         |  6/19  |        |        |        |        |        |        |
| TIROS-M  Sssssssssssssssss  |        |        |        |        |        |        |
|          |      12/11  8/19 |        |        |        |        |        |        |
| NOAA-1   |        Ssssssss  |        |        |        |        |        |        |
|          |        |    10/21|        |        |        |        |        |        |
| ITOS-B   |        |       0 |        |        |        |        |        |        |
|          |        |         |    10/15 3/19   |        1/30     |        |        |
| NOAA-2   |        |         |      Sssss]sssssssssssssssssssss  |        |        |
|          |        |         |        |  7/16  |        |        |        |        |
| ITOS-E   |        |         |        |   0    |        |        |        |        |
|          |        |         |        |    11/6 3/3     |        |   8/31 |        |
| NOAA-3   |        |         |        |      Sss]sssssssssssssssssssssssssssss  |        |
|          |        |         |        |        |     11/15       |2/2     |2/2     |
| NOAA-4   |        |         |        |        |        Sssssssssssss]ssssssssss]sssssssss|
|          |        |         |        |        |        |        |   7/29 |        |
| NOAA-5   |        |         |        |        |        |        |     Sssssssssssssss|
|----------------------------------------------------------------------------|
|          |  1978  |  1979  |  1980  |  1981  |  1982  |  1983  |  1984  |        |
|----------------------------------------------------------------------------|
| (NOAA-4  |2/24  8/6 11/18   |        |        |        |        |        |        |
| Cont.)   |s]sssss]sss|      |        |        |        |        |        |        |
| (NOAA-5  |        | 3/16 7/16 |      |        |        |        |        |        |
| Cont.)   |s]sssssssssssss]ssss |    |        |        |        |        |        |
|          |     10/13        |        |2/27    |        |        |        |        |
| TIROS-N  |      Pppppppppppppppppppppppppppppp  |        |        |        |        |
|          |        |  6/27   |        |        |        |     9/29        |        |
| NOAA-6   |        |  Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa]----------]--------aaaaaa |
|          |        |         |  5/29  |        |        |        |        |        |
| NOAA-B   |        |         |   0    |        |        |        |        |        |
|          |        |         |        |  6/23  |        |        |        |        |
| NOAA-7   |        |         |        |  Ppppppppppppppppppppppppppppppppppppppppppp |
|          |        |         |        |        |        |  3/28  |  7/1   |        |
| NOAA-8   |        |         |        |        |        |  Aaaaaaaaaaaaaa |        |
------------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
P = Launch of a satellite in the afternoon orbit
A = Launch of a satellite in the morning orbit
] = Partial failure on-orbit
O = Launch failure

ANALYSIS

WE FOUND NO ELEGANT CLOSED SOLUTION, SO WE USED "BRUTE FORCE"

ANALYZED 121 SCENARIOS

USED NOMINAL PLANNING SCENARIOS AS A BASELINE

- 18-MONTH LAUNCH CENTERS AND NO FAILURES FOR ONE-SATELLITE SYSTEM
- 12-MONTH LAUNCH CENTERS, NO FAILURES, AND NO EXTENDED LIFE FOR TWO-SATELLITE SYSTEM

VARIED

- FAILURES AND SEQUENCES OF FAILURES
- EXTENDED LIFETIMES AND SEQUENCES OF THESE
- DESIGN LIFETIME (24, 28, AND 32 MONTHS)
- LAUNCH SCHEDULES
  - -- 12, 14, AND 16 MONTHS FOR TWO-SATELLITE SYSTEM
  - -- 18, 20, AND 22 MONTHS FOR ONE-SATELLITE SYSTEM
- CALL-UP SCHEDULE (4 MONTHS, 6 MONTHS, 9 MONTHS OR NO CALL-UP)
- CREDIT FOR EXTENDED LIFE (YES OR NO)
- WARNING OF IMMINENT FAILURE (YES OR NO)

MEASURED

- SERVICE (IN PERCENTAGE OF TIME)
  - -- AT LEAST ONE SATELLITE
  - -- IMPROVED WITH DUAL SATELLITES (TWO-SATELLITE SYSTEM ONLY)
  - -- DEGRADED WITH AM SATELLITE ONLY (TWO-SATELLITE SYSTEM ONLY)
- COSTS (DOMINATED BY THE NUMBER OF SATELLITES NEEDED, BUT INCLUDING LAUNCH USER CHARGES AND OPERATIONS COSTS)

SUMMARY FINDINGS

IMPROVEMENTS IN SERVICE AND REDUCTIONS IN COST

	Satellites Launched	Data Service (percent of the time)			
		No Data	AM Only	PM Only	Dual
CONVENTIONAL PLANNING SCENARIOS (NO FAILURES) -- HIGHLY IMPROBABLE					
One-Satellite System	11	0	NA	NA	NA
Two-Satellite System	16	0	0	0	100
PROBABLE SCENARIOS WITH FAILURES, NO CALL-UP REPLACEMENT LAUNCHES					
One-Satellite System	11	30	NA	NA	NA
Two-Satellite System	16	8	15	18	59
PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES 4 MONTHS AFTER A FAILURE					
One-Satellite System	13	6	NA	NA	NA
Two-Satellite System	20	4	3	19	74
PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES AND EXTENDED LIFE*					
One-Satellite System	12	0-2	NA	NA	NA
Two-Satellite System	12-13**	0-1	6	12	81

* In the one-satellite system, extended life helps service when it occurs; in the two-satellite system, we launch on failure.

** 13th launch near the end of the 15th year.

SELECTED SCENARIOS FOR A TWO-SATELLITE SYSTEM

Management Strategy	Baseline No Call-up	Baseline With Call-up	A*	B	C**
Call-up Time (mo.)	None	4	4	4	4
Planned Life (mo.)	24	24	32	28	no fail.
Launch on Failure	No	No	No	No	Yes
Launch Sched. (mo.)	12	12	16	14	varies
Service (% of time)					
Meet Minimum Goal	92	96	97	98	98-100
(PM only)	25	26	24	21	12
(AM only)	15	3	2	1	6
Dual	52	67	72	76	81
Number of Satellites	16	20	17	16	12

* No 32-month satellite design has been proposed; used here to illustrate effect.

** Best management strategy.

SELECTED SCENARIOS FOR A ONE-SATELLITE SYSTEM

Management Strategy	Baseline No Call-up	Baseline With Call-up	A*	B**
Call-up Time (mo.)	None	4	4	4
Planned Life (mo.)	24	24	32	28
Launch on Failure	NA		No	No
Launch Schedule (mo.)	18	18	22	20
Service (% of time)				
Meet Minimum Goal	70-80	90	100	100
(PM only)	70-80	90	100	100
(AM only)	--	--	--	
Dual	--	--	--	
Number of Satellites**	11	13	11	12

* No 32-month satellite design has been proposed; used here to illustrate effect.

** Best management strategy.

BEST ONE-SATELLITE MANAGEMENT STRATEGY

THERE ARE FIVE FUNDAMENTAL PRINCIPLES:

- PROCURE ENOUGH SATELLITES ON SUCH A SCHEDULE THAT ONE IS ALWAYS READY TO BACK UP A FAILED SATELLITE OR A LAUNCH FAILURE
- ARRANGE FOR A 4-MONTH CALL-UP CAPABILITY
- TAKE ADVANTAGE OF EXTENDED LIFETIMES BY PLANNING ON AN AVERAGE LIFETIME LIKE THAT OF RECENT EXPERIENCE (NAMELY, 28 MONTHS)
- LAUNCH AT REGULAR INTERVALS SHORTER THAN THE EXPECTED LIFETIME
- LAUNCH BEFORE THE 20-MONTH NOMINAL LAUNCH PERIOD IF THERE ARE INDICATIONS OF IMMINENT FAILURE

BEST TWO-SATELLITE MANAGEMENT STRATEGY

THE BEST PLAN TAKES FULL ADVANTAGE OF EXTENDED LIFETIMES.

THERE ARE FOUR FUNDAMENTAL PRINCIPLES:

- PROCURE ENOUGH SATELLITES ON SUCH A SCHEDULE THAT ONE IS ALWAYS READY TO BACK UP A FAILED SATELLITE OR A LAUNCH FAILURE

- ARRANGE FOR A 4-MONTH CALL-UP CAPABILITY

- TAKE ADVANTAGE OF EXTENDED LIFETIMES BY DELAYING THE LAUNCH OF REPLACEMENT SATELLITES UNTIL THERE IS A FAILURE

- LAUNCH EARLIER THAN PLANNED IF THERE ARE INDICATIONS OF IMMINENT FAILURE

ANALYSIS OF NUMBER OF SATELLITES NEEDED

	ONE SATELLITE	TWO SATELLITES
REPEAT OF HISTORY*	12	12-13
NOMINAL PLANNING SCENARIO (POOR SERVICE)	11	16
INFANT MORTALITY (ELV AND S/C)**	12***	15

THEREFORE, THE NUMBER OF SATELLITES TO BUY FOR THE NEXT 15 YEARS (ASSUMING CONTINUATION OF PRESENT EXPENDABLE FREE FLYERS)

PROCURE

- FOR A ONE-SATELLITE SYSTEM, 12
- FOR A TWO-SATELLITE SYSTEM, 12

IN WORST CASE MAY NEED MORE

- FOR A ONE-SATELLITE SYSTEM, NONE (MAYBE 1)
- FOR A TWO-SATELLITE SYSTEM, 3 (OR 4)

---

* Assumes near duplication (and repeat) of the past 7 years.

** Assumes failure of first models of refurbished TITAN Expendable Launch Vehicle (ELV) and failure of first copies of the new design "NOAA-NEXT."

*** Cannot recover, data gaps occur.

GENERAL FINDINGS

SERVICE

BOTH SYSTEMS CAN BE MANAGED TO PROVIDE REASONABLE ASSURANCE OF THE MINIMUM SERVICE GOAL

THE TWO-SATELLITE SYSTEM IS GENERALLY MORE ROBUST THAN THE ONE-SATELLITE SYSTEM IN THE WORST SCENARIOS

LARGEST IMPROVEMENT IN SERVICES COMES FROM SHORTEST CALL-UP (IN BOTH SYSTEMS)

ADDITIONAL IMPROVEMENTS IN SERVICE COME IF WE ASSUME A LONGER DESIGN LIFE (WHILE HOLDING SHORTER LAUNCH CENTERS) AND ASSUME THERE ARE EARLY INDICATIONS OF IMMINENT FAILURE

COSTS

REDUCTIONS IN COST CAN BE MADE IN BOTH SYSTEMS BY ASSUMING A LONGER DESIGN LIFE

THE LARGEST REDUCTION IN COST COMES IN THE TWO-SATELLITE SYSTEM BY TAKING ADVANTAGE OF EXTENDED LIFETIMES

LIMITATIONS OF THE ANALYSIS

WE DID NOT ANALYZE ALL POSSIBLE SCENARIOS

- DOES NOT GIVE PRECISE SERVICE STATISTICS AND COSTS
- ADEQUATE TO ESTABLISH THE MANAGEMENT PRINCIPLES
- GIVES REASONABLE BOUNDS ON THE NUMBER TO BUY

LIMITED TO CONTINUATION OF PRESENT APPROACHES

- DID NOT ANALYZE SPACE STATION
- DID NOT ANALYZE WHAT IT WOULD COST TO IMPROVE RELIABILITY
- DID NOT ANALYZE SPACE TRANSPORTATION SYSTEM (STS) LAUNCH (BUT SHOULD MAKE NO DIFFERENCE)

THIS IS A PROGRAM MANAGEMENT ANALYSIS, <u>NOT</u> A BUDGET ANALYSIS

I. SUMMARY

Based on the experience of the past 15 years, the best management strategy to apply to the Polar-orbiting Operational Environmental Satellite (POES) system for the next 15 years was established. This was done for both a two-satellite configuration and a one-satellite configuration. The strategy includes always having a spare available, a 4-month call-up capability, taking advantage of satellites that live longer than their design lifetimes, and taking advantage of early indications of imminent on-orbit failure when they occur. These principles must be applied in different ways to the two configurations.

Applying these principles to several scenarios for the future POES leads to the conclusion that we should plan for 12 satellites during the next 15 years for <u>either</u> the one-satellite system or the two-satellite system.

A. Background

Past planning for the POES system by the National Oceanic and Atmospheric Administration (NOAA) has assumed the launch of satellites at fixed intervals. These fixed intervals were derived from the design lifetime of the spacecraft, which for the present satellites is 2 years.

For the traditional two-satellite system, one satellite was placed in the afternoon (PM) orbit to provide the prime data (both temperature soundings and imagery) in response to the highest priority needs of the National Weather Service (NWS). A second satellite was placed in a morning (AM) orbit to provide backup to the first in the event of its failure. This second satellite also provides additional data to the NWS when both satellites are operating. Planning scenarios assumed a launch each year to alternately replace the PM or AM satellites. A schedule for such a scenario would look like that in Figure I-1.

A cursory examination of the actual POES history over the past 15 years shows that there is almost no similarity between the planning scenario and actual events. In fact, there were three launch failures, and two satellites failed before the end of their design lifetimes. Eight satellites lived longer than the design life. Thirteen satellites were needed over the 15-year period. The first eight satellites in this period were designed as a one-satellite system, with one-year lifetimes. They operated in a higher orbit than now used, with fully redundant instruments aboard. They provided services for the first 8 of these 15 years. Five satellites of the present design, with redundancy provided by orbiting a second satellite, provided services over the last 7 years. A sixth satellite was launched at the very end of the 15th year. The average lifetime of

Figure I-1

Conventional planning for a two-satellite POES system

```
24-Month Design Life              ¦        No Random Launch Failures
12-Month Launch Interval          ¦          No Premature Failures
--------------------------------------------------------------------

MONTHS  10      20      30      40      50      60      70      80      90      100     110
         ¦       ¦       ¦       ¦       ¦       ¦       ¦       ¦       ¦       ¦       ¦
1                  24
Pppppppppppppppppppppppp
         12                36
2     (2) Aaaaaaaaaaaaaaaaaaaaaaaa
                   24                48
3              (3) Pppppppppppppppppppppppp
                           36                60
4                      (4) Aaaaaaaaaaaaaaaaaaaaaaaa
                                     48                72
5                                (5) Pppppppppppppppppppppppp
                                             60                84
6                                        (6) Aaaaaaaaaaaaaaaaaaaaaaaa
                                                       72                96
7                                                  (7) Pppppppppppppppppppppppp
                                                               84                108
8                                                          (8) Aaaaaaaaaaaaaaaaaaaaaaaa
                                                                         96        (110)
9                                                                    (9) Pppppppppppppp
                                                                                 108(120)
10                                                                           (10) Aaa
--------------------------------------------------------------------
MONTHS          110     120     130     140     150     160     170     180
                 ¦       ¦       ¦       ¦       ¦       ¦       ¦       ¦
                         120
9 continued     pppppppppp
                                 132
10 continued    aaaaaaaaaaaaaaaaaaaaaa
                         120               144
11                  (11) Pppppppppppppppppppppppp
                                 132                156
12                          (12) Aaaaaaaaaaaaaaaaaaaaaaaa
                                           144                168
13                                    (13) Pppppppppppppppppppppppp
                                                    156                180
14                                             (14) Aaaaaaaaaaaaaaaaaaaaaaaa
                                                              168     (180)
15                                                       (15) Pppppppppppp  192
                                                                       180
16                                                                (16) A  224
--------------------------------------------------------------------
```

LEGEND

P = Launch of a satellite into the afternoon orbit
A = Launch of a satellite into the morning orbit

satellites of the current design has been 30 months (as of March 1985). The actual sequence of events over the past one and one-half decades is shown in Figure I-2.

The actual events did not parallel the planning scenario because of launch failures, the early failures of some of the satellites, and longer lifetimes than expected for some of the satellites. NOAA "called up" replacement satellites when a launch vehicle failed, or when an on-orbit satellite failed early. Some launches were delayed when a satellite was operating far beyond its design life. NOAA did not slavishly follow the formula set out in the budget planning scenario, but managed the system to provide the best service with the fewest satellites.

NOAA now has enough experience with satellites of modern design to analyze past experiences, and to codify the management principles that will lead to the best service at the least cost in the future.

In recent years, the Administration has decided to change to a POES system with only one satellite providing services in the prime afternoon orbit. Such a one-satellite system can be planned with launches at intervals just short of the design life to allow time to launch and check out a replacement in the event of a launch failure, thus assuring that there will not be a long gap between two satellites. In planning this system, NOAA used a launch interval of 18 months. The planning scenario thus derived is shown in Figure I-3.

B. Purpose

The purposes of the study reported in this document were (1) to derive the best POES management strategies or principles applicable to the operation of either the traditional two-satellite system or the currently planned one-satellite system, and (2) to determine the number of satellites that should be procured in order to provide reliable services during the next 15 years for either system configuration.

C. Approach

Goals for services from the POES system were established. These were derived from documented requirements of the National Weather Service and other users, and from NOAA's experience. The minimum POES service goal thus established is to provide prime mission data services (soundings and imagery) from one satellite at all times. Data from satellites in the afternoon orbit are more important to the NWS in its numerical

Figure I-2

History of the
POES system since 1970

```
-----------------------------------------------------------------------------
| Satellite|                            Years                                 |
|---------------------------------------------------------------------------|
|          |  1970   |  1971   |  1972   |  1973   |  1974   |  1975   |  1976   |  1977   |
|---------------------------------------------------------------------------|
|       1/23        |  6/19   |         |         |         |         |         |         |
| TIROS-M  Sssssssssssssssss   |         |         |         |         |         |         |
|          |       12/11  8/19 |         |         |         |         |         |         |
| NOAA-1   |         Ssssssss  |         |         |         |         |         |         |
|          |         |   10/21 |         |         |         |         |         |         |
| ITOS-B   |         |       0 |         |         |         |         |         |         |
|          |         |         |     10/15 3/19    |         |  1/30   |         |         |
| NOAA-2   |         |         |       Sssss]ssssssssssssssssssssss |         |         |
|          |         |         |         |   7/16  |         |         |         |         |
| ITOS-E   |         |         |         |     0   |         |         |         |         |
|          |         |         |         |     11/6 3/3      |         |   8/31  |         |
| NOAA-3   |         |         |         |        Ssss]sssssssssssssssssssssssssssss |         |
|          |         |         |         |         |    11/15          |2/2      |2/2      |
| NOAA-4   |         |         |         |         |         Sssssssssssss]ssssssssss]sssssssss|
|          |         |         |         |         |         |         |   7/29  |         |
| NOAA-5   |         |         |         |         |         |         |     Ssssssssssssssss|
|---------------------------------------------------------------------------|
|          |  1978   |  1979   |  1980   |  1981   |  1982   |  1983   |  1984   |         |
|---------------------------------------------------------------------------|
| (NOAA-4  |2/24  8/6 11/18    |         |         |         |         |         |         |
| Cont.)   |s]sssss]sss|       |         |         |         |         |         |         |
| (NOAA-5  |         | 3/16 7/16         |         |         |         |         |         |
| Cont.)   |s]ssssssssssss]ssss|         |         |         |         |         |         |
|          |     10/13         |         |2/27     |         |         |         |         |
| TIROS-N  |         Pppppppppppppppppppppppppppp   |         |         |         |         |
|          |         |  6/27   |         |         |         |         9/29      |         |
| NOAA-6   |         |   Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa]---------]--------aaaaaa   |
|          |         |         |  5/29   |         |         |         |         |         |
| NOAA-B   |         |         |   0     |         |         |         |         |         |
|          |         |         |         |   6/23  |         |         |         |         |
| NOAA-7   |         |         |         |     Pppppppppppppppppppppppppppppppppppppppppp  |
|          |         |         |         |         |         |  3/28   |   7/1   |         |
| NOAA-8   |         |         |         |         |         |   Aaaaaaaaaaaaaa  |         |
-----------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
P = Launch of a satellite in the afternoon orbit
A = Launch of a satellite in the morning orbit
] = Partial failure on-orbit
--- = Standby status

Figure I-3

Conventional planning for a one-satellite POES system

```
24-Month Design Life                  |        No Random Launch Failures
18-Month Launch Interval              |            No Premature Failures
---------------------------------------------------------------------------
MONTHS  10     20     30     40     50     60     70     80     90    100    110
        |      |      |      |      |      |      |      |      |      |      |
1                 24
Ssssssssssssssssssssssss
                  18               42
2               (2) Ssssssssssssssssssssssss
                             36                60
3                          (3) Ssssssssssssssssssssssss
                                         54               78
4                                     (4) Ssssssssssssssssssssssss
                                                     72              96
5                                                 (5) Ssssssssssssssssssssssss
                                                                90           (110)
6                                                           (6) Sssssssssssssssssssss
                                                                          108(110)
7                                                                         (7) Sss
---------------------------------------------------------------------------
MONTHS              110    120    130    140    150    160    170    180
                    |      |      |      |      |      |      |      |
                       114
6 continued         sssss
                                      132
7 continued         ssssssssssssssssssssssss
                             126               150
8                          (8) Ssssssssssssssssssssssss
                                         144              168
9                                     (9) Ssssssssssssssssssssssss
                                                     162           (180)
10                                              (10) Ssssssssssssssssss  186
                                                                   180
11                                                            (11) S  204
---------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system

weather forecasting than are data from satellites in the morning orbit. Extra data from a second satellite are of considerable value to weather forecasters, and providing this extra data is a secondary POES goal. Some degradation in service (but not complete loss of service) may be acceptable for brief periods, perhaps a few weeks at a time.

Over 120 scenarios were examined, each with different system management approaches or different assumed sequences of satellite successes and failures. These tests were rated to determine which management approaches best met the POES service goals. From this part of the study, a set of management principles was derived for the one-satellite system and a different set for the two-satellite system.

These principles were applied to possible future scenarios to determine how many satellites would be needed over the next 15 years for both the one- and two-satellite systems. From these, the management strategies that gave the best service at the least cost, as measured by the number of satellites required, were determined.

D. Analysis

In the more than 120 scenarios constructed, the number and timing of launch failures were varied within reasonable bounds, based on past experience. The timing of on-orbit failure of satellites was also varied using past experience as a guide. Similarly, the on-orbit lifetimes of the satellites followed patterns established by experiences of the POES over the past 15 years. (See Table I-1.)

Table I-1

PAST PERFORMANCE

THREE LAUNCH FAILURES OVER 15 YEARS

TWO SATELLITES FAILED TO REACH THEIR DESIGN LIFE

- 9 MONTHS (12-MONTH DESIGN)
- 15 MONTHS (24-MONTH DESIGN)

EIGHT EXCEEDED THEIR DESIGN LIFETIMES

- 17 MONTHS (12-MONTH DESIGN)
- 28 MONTHS (12-MONTH DESIGN)
- 34 MONTHS (12-MONTH DESIGN)
- 49 MONTHS (12-MONTH DESIGN)
- 37 MONTHS (12-MONTH DESIGN)
- 30 MONTHS (14-MONTH DESIGN)
- 52 (OR 66) MONTHS (24-MONTH DESIGN)
- 42 MONTHS AND STILL OPERATING (24-MONTH DESIGN)

Different system management approaches were applied to these results. The baseline used in either system configuration was satellite lifetimes and launch schedules assumed in the budget planning scenarios (Figures I-1 and I-3). Calling up replacements, under different assumed launch delays that range from 4 to 9 months, was added. Both the planned on-orbit lifetimes and the fixed launch schedule were extended slightly in some tests. When possible in some tests, advantage was taken of on-orbit lifetimes considerably in excess of the average recently experienced, and of early warnings of imminent on-orbit failure, if they are detectable. (See Table I-2.)

Table I-2

SUMMARY OF ANALYSIS METHODS

ANALYZED 121 SCENARIOS

VARIED

- FAILURES AND SEQUENCES OF FAILURES
- EXTENDED LIFETIMES AND SEQUENCES OF THESE
- DESIGN LIFETIME (24, 28, AND 32 MONTHS)
- LAUNCH SCHEDULES
  - -- 12, 14, AND 16 MONTHS FOR TWO-SATELLITE SYSTEM
  - -- 18, 20, AND 22 MONTHS FOR ONE-SATELLITE SYSTEM
- CALL-UP SCHEDULE (4 MONTH, 6 MONTH, 9 MONTH, OR NO CALL-UP)
- WHETHER WE TOOK CREDIT FOR EXTENDED LIFE (YES OR NO)
- WHETHER THERE WAS WARNING OF IMMINENT FAILURE (YES OR NO)

MEASURED

- SERVICE (IN PERCENTAGE OF TIME)
  - -- AT LEAST ONE SATELLITE
  - -- IMPROVED WITH DUAL SATELLITES (TWO-SATELLITE SYSTEM ONLY)
  - -- DEGRADED WITH AM SATELLITE ONLY (TWO-SATELLITE SYSTEM ONLY)
- COSTS (DOMINATED BY THE NUMBER OF SATELLITES NEEDED, BUT INCLUDING LAUNCH USER CHARGES AND OPERATIONS COSTS)

USED NOMINAL PLANNING SCENARIOS AS A BASELINE

- 18-MONTH LAUNCH CENTERS AND NO FAILURES FOR ONE-SATELLITE SYSTEM
- 12-MONTH LAUNCH CENTERS, NO FAILURES, AND NO EXTENDED LIFE FOR TWO-SATELLITE SYSTEM

Table I-3

Summary table showing the number of satellites launched and the system performance statistics of the POES system under different planning assumptions

	Satellites Launched	Data Service Statistics (percent of the time)			
		No Data	AM Only	PM Only	Dual*
<u>CONVENTIONAL PLANNING SCENARIOS (NO FAILURES) HIGHLY IMPROBABLE</u>					
One-Satellite System	11	0	NA	NA	NA
Two-Satellite System	16	0	0	4	96
<u>PROBABLE SCENARIOS WITH FAILURES, WITHOUT CALLING UP REPLACEMENT LAUNCHES</u>					
One-Satellite System	11	30	NA	NA	NA
Two-Satellite System	16	8	15	25	52
<u>PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES 4 MONTHS AFTER A FAILURE</u>					
One-Satellite System	13	6	NA	NA	NA
Two-Satellite System	20	4	3	26	67
<u>PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES AND EXTENDED LIFE</u>					
One-Satellite System	12	0-2	NA	NA	NA
Two-Satellite System	12 or 13	0-1	6	19	74

* These percentages, as determined from the figures, include a startup period between the launches of the first and second satellites when only a single satellite is on orbit. If this analysis were made of a system in being, as is the present situation, the four percentages of time with dual data services in a two-satellite system shown in this column would be 100, 59, 74, and 81.

The summary of some of these tests, shown in Table I-3, demonstrates the results of progressively varying some of the management parameters. Adding the call-up capability significantly increases the number of satellites needed in either system configuration, but dramatically improves the services. Taking advantage of extended lifetimes substantially reduces the number of satellites needed in the two-satellite system, without significantly degrading the service.

The system management approaches that almost always give the best service performance in the modeled scenarios include just a few principles for the two-satellite system, and a few slightly different principles for the one-satellite system.

For the two-satellite system, the best management principles derived from the analysis are:

- procure sufficient satellites on a schedule such that one satellite is always available to back up a failed satellite on orbit or to replace one that fails at launch;

- arrange for a short (4 months) call-up capability;

- take advantage of extended on-orbit lifetimes by delaying the launch of replacements until there is a failure; and

- launch as soon as possible (4 months) if there are indications of imminent on-orbit failure.

The best management principles for the one-satellite system varied somewhat because it was not possible to take advantage of a second satellite to back up an aging or prematurely failed primary satellite. Thus, fixed launch schedules had to be based on the <u>average</u> life that could be expected from the satellites. These management principles for the one-satellite POES system are:

- procure enough satellites on a schedule such that one is always available to back up a failed satellite or to replace one that fails at launch;

- arrange for a short (4 months) call-up capability;

- take advantage of extended lifetimes by planning on the <u>average</u> lifetime of recent experience, rather than the present nominal design life;

- launch at regular intervals that are shorter than the expected average lifetime (i.e., 20 months for this analysis) to allow time to launch replacements after launch failures; and

* launch before the next regularly scheduled attempt if there are indications of an imminent on-orbit failure.

Having established these best management principles and finding that they gave very acceptable projected service, the number of satellites necessary for the next 15 years was specifically examined. It is impossible to examine all eventualities, but it is possible to place some bounds on the results.

Using the nominal planning scenarios, the two-satellite system would require 16 satellites over 15 years, but would not give acceptable service. The one-satellite system would require 11 satellites as nominally planned, but would give even worse service. These scenarios were used only as baselines against which other POES management plans could be compared.

One practical way to look into the future, in the absence of a crystal ball, is to assume that history will repeat itself. Such an approach has the added merit that the probabilities are exactly those derived from past experiences. The management principles were tried in "repeat of history" scenarios.

Tables I-4 and I-5 show some selected results from the previous analysis of many scenarios, along with the analysis of this "repeat of history" planning approach. This last approach is shown in the last column of these tables. The one-satellite system approach used an average of events that have occurred, assuming three launch failures over the next 15 years. The two-satellite approach is based on an exact repeat of historical events, with three assumed launch failures during the next 15 years.

In both the one-satellite and two-satellite systems, much better services are provided if a 4-month call-up is added to the baseline planning scenarios. In both systems, planning on average lifetimes of 28 rather than 24 months reduces the number of needed satellites (Case B in Table I-4 and Case A in Table I-5). The greatest reduction in the number of satellites needed in the two-satellite system occurs when a substantial advantage can be taken of any long-lived satellites, because a backup is on orbit. This is shown in Case C in Table I-5.

There is another way to apply the lessons of the past to the future, and it gives rise to what may be the worst case likely to be experienced by the POES in the future. "Infant mortality" problems can be expected to occur with satellites of any new design that may follow those satellites of the present design now in procurement. These problems in the future POES could give rise to a clustering of shortened on-orbit lifetimes from early "NOAA-NEXT" satellites, combined with initial launch failures of the "new" TITAN II vehicles.

Table I-4

Selected scenarios for the one-satellite POES system

	Baseline Without Call-up	Baseline With Call-up	Case A	Case B *
System Assumptions				
Call-up period	None	4 month	4 month	4 month
Planned life	24 month	24 month	32 month	28 month
Launch on failure	N/A	N/A	No	No
Launch schedule	18 month	18 month	22 month	20 month
Service (% Time)				
Meet Minimum Goal	70 to 80	90	100	100
PM data only	70 to 80	90	100	100
AM data only	N/A	N/A	N/A	N/A
Dual data service	N/A	N/A	N/A	N/A
Satellites required**	11	13	11	12

* System management plan of choice
** Assuming three launch failures

Table I-5

Selected scenarios for the two-satellite POES system

	Baseline Without Call-up	Baseline With Call-up	Case A	Case B	Case C*
System Assumptions					
Call-up period	None	4 month	4 month	4 month	4 month
Planned life	24 month	24 month	28 month	32 month	On Failure
Launch on failure	No	No	No	No	Yes
Launch schedule	12 month	12 month	14 month	16 month	Various
Service (% Time)					
Meet Minimum Goal	92	96	98	98	98 to 100
PM data only	25	26	24	21	12
AM data only	15	3	2	1	6
Dual data service	52	67	72	76	81
Satellites required**	16	20	17	16	12

* System management plan of choice
** Assuming three launch failures

In scenarios prepared to test these "worst likely" assumptions, both systems, identified in Tables I-4 and I-5 as "system management plans of choice," handled the severe circumstances rather well. The one-satellite plan experienced two short periods (one of 4 months and one of 2 months) of total loss of service. In the two-satellite management plan, there could be a 4-month gap if there were no early indications of on-orbit failure. This gap would be eliminated if early indications were present. The one-satellite system did not require more than the 12 satellites needed in previous scenarios in order to handle these severe circumstances. In the two-satellite system, three or four additional satellites were required. The two-satellite system continued to provide substantially better service in this test, demonstrating its greater robustness. That extreme robustness, if exercised, comes at some additional cost in the long term.

E. Findings and Conclusions

The best management principles for the POES system are largely independent of whether the system is configured with one satellite or two, but application of the principles is different in two important ways.

The common principles include:

(1) providing enough satellites so that there is always one available on the ground to be called up to replace a satellite that fails on orbit or at launch;

(2) reducing as much as possible the call-up delay (if this delay is longer than 4 months, services can be significantly degraded); and

(3) taking advantage of indications of imminent failure to call up a replacement satellite.

Differences in the way these principles are applied are:

(1) in the one-satellite extended-life system, using the average length of recent on-orbit lifetimes permits the system to be planned on assumed 28-month on-orbit lifetimes, with launches regularly scheduled every 20 months; and

(2) in the two-satellite extended-life system, launching satellites only after failures permits taking advantage of long on-orbit lifetimes when they occur, while protecting services by promptly (in 4 months) launching replacements when there are failures.

The number of satellites likely to be needed is independent of the system configuration. Twelve satellites are required to provide coverage over the 15-year period for either a one- or two-satellite system. This is due largely to the ability of the two-satellite system to take advantage of satellites that remain operational beyond their design lifetimes, when the management principles developed here are applied.

II. BACKGROUND AND PURPOSE

A. Purpose of the Study

The National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA) has 25 years of experience in operating the Polar-orbiting Operational Environmental Satellite (POES) system. A number of changes took place in the system over the first 18 years, but over the last 7 years the system has been largely the same in its instrument complement, spacecraft, and launch vehicles, and the way in which the system has been operated. This experience provides the basis for reflecting on the future of the POES.

This study is aimed at determining the best way to operate the system for the rest of the century and how many satellites NOAA should procure for that period so that the system can be managed in an optimum manner. The study covers both the two-satellite system that has been traditional, and the one-satellite system that has been considered during the last few years.

THE GOALS OF THE STUDY WERE:

TO DEFINE THE OPTIMUM STRATEGIES FOR MANAGING THE POES (I.E., BEST SERVICE AT LOWEST COST)

- IN A ONE-SATELLITE CONFIGURATION
- IN A TWO-SATELLITE CONFIGURATION

TO DETERMINE HOW MANY SATELLITES SHOULD BE PROCURED FOR THE REST OF THE DECADE

- FOR A ONE-SATELLITE SYSTEM
- FOR A TWO-SATELLITE SYSTEM

The optimum management approach for either a one-satellite or a two-satellite POES system is one that will (1) provide fully reliable data services at all times, (2) respond to the highest priority requirements of the National Weather Service (NWS) and the rest of the user community at large, (3) provide some additional services above those minimally acceptable, and (4) keep the long-term costs to the lowest possible level.

In managing the POES system, the most important service goal is to ensure that data from at least one satellite is available 100 percent of the time, preferably from satellites in an early afternoon (PM) orbit. This is the minimally acceptable service goal if the POES is to meet the highest priority NWS requirements for data from the polar-orbiting satellites.

Periods of time when no satellite data are available are unacceptable to the NWS. The lack of temperature sounding data reduces the accuracy of NWS medium-range (3 to 5 days) and long-range (5 to 8 days) weather forecasts. The loss of imagery reduces the ability to forecast severe weather events, especially in areas like Hawaii and Alaska that are outside the optimum coverage of the geostationary satellites.

In a two-satellite system, continuity of data services is provided by having a second satellite in orbit act as a backup to the preferred PM satellite. To provide additional coverage (i.e., more soundings at different times of day), the backup satellite is placed in a different (morning or AM) orbit.

Operating two satellites in different orbits also reduces the demands on the facilities and personnel at the Command and Data Acquisition Stations and the Satellite Operations Control Center, permits more efficient use of radio communications frequencies, and smooths the workload in the data processing and information extraction programs. Data from satellites in this morning orbit are an acceptable short-term substitute for the preferred PM data.

When the two-satellite system provides both PM and AM data (referred to in this report as "dual data"), there are substantial benefits to NWS weather forecasting and climate programs. Additional satellite coverage improves the long-term forecasts by providing soundings at the proper time for incorporation in the numerical models in geographic regions where data are not available from satellites in the afternoon orbit. Weather forecasters in some regions of the world are entirely dependent on the images from NOAA's polar orbiters for their large-scale observations. Interruption of that data flow is tantamount to interruption in their forecasting services. Other users of POES services (e.g., Search and Rescue, agricultural users) are also better served.

In a one-satellite system, an attempt would be made to maintain continuity of service by launching satellites into the PM orbit on an assured schedule, presumably before the expected end of life of satellites on orbit. No additional data would be available at any other time of the day.

There are four possible situations that could prevail during the POES program, and they are of unequal desirability. Discounting partially operational satellites, they are:

- One PM and one AM satellite ---- better than nominal
- One PM satellite --------------- nominal and required
- One AM satellite --------------- acceptable for short periods
- No satellites ----------------- unacceptable for any period

The conventional planning for both budget and procurement (shown in Figures I-1 and I-3) assumes average conditions over a long period of time, with launches on a fixed schedule derived from those average conditions. In fact, some launch failures will occur, and satellites will have variable lifetimes on orbit, with some satellites lasting considerably longer than the nominal design life and others failing early.

NOAA has operated the POES system in the past to accommodate these failures, but the means for such accommodations are not apparent in the planning scenarios. A complete understanding of the probabilities of failures, and of their impact on service, is important in determining the optimum management approach for the POES and in assessing the relative costs to operate either a one-satellite or two-satellite system.

The first objectives of this study of the long-term POES system are to understand fully the possible and probable launch failures or failures on orbit before the end of the design lifetime of the satellites, and to understand the impact of these failures on services to the National Weather Service and the larger user community.

Based on this understanding, the study's objectives are to define a management approach for the POES system that will:

- mitigate the interruptions in services to data users to the maximum extent possible, and

- provide optimum data services to the NWS and the rest of the user community at the lowest possible cost.

The final objective is to determine the prudent number of satellites for which to plan during the next 15 years for either the two-satellite system or the one-satellite system.

B. History of the POES Since 1970

The basis for any planning is the past. This year marks the 25th anniversary of the first launch of an operational weather satellite, on April 1, 1960. The past 15 years of experience is quite relevant to future planning.

During the period from the first month of 1970 through the last month of 1984, there were 13 NOAA polar-orbiting satellite launches attempted using expendable launch vehicles. Three of the 13 failed to achieve orbit.

The first eight satellites in the series (TIROS-M through NOAA-5) were designed for single satellite coverage in a higher orbit, with fully redundant instruments. They had a

1-year design life. They provided service for 8 of the 15 years. The average life of all eight satellites was just over 1 year. The average on-orbit life of those that reached orbit was 1.4 years.

The last six satellites in the series (TIROS-N to NOAA-8) provided 7 years of service. They could not carry dual instruments, and were thus designed for two-satellite coverage to provide redundancy. Except for the first satellite in this series, TIROS-N, which had a design life of 14 months, these satellites had design lifetimes of 2 years.

Since the first of the current generation of POES satellites was launched in 1978, (1) Television and Infrared Observation Satellite (TIROS)-N provided 29 months of prime mission data services (both imagery and soundings), (2) NOAA-6 achieved 41 months of service, (3) NOAA-B failed to achieve orbit, (4) NOAA-7 lasted 37 months, and (5) NOAA-8 failed after 15 months. The average lifetime of all five satellites in this series was 24.4 months, with an average lifetime of the four that reached orbit of 30.5 months. This history is shown in Figure I-2, and summarized briefly as follows:

1. TIROS-M (NASA funded) was launched January 23, 1970, with a design life of 12 months in a one-satellite system. It was deactivated June 19, 1971, after 16.8 months of service, due to the failure of a motor.

2. NOAA-1 was the first of the series procured by NOAA. It was launched December 11, 1970, with a design life of 12 months in a one-satellite system. It was deactivated August 19, 1971, after 9.3 months.

3. ITOS-B failed to achieve orbit on October 21, 1971.

4. NOAA-2 was launched October 15, 1972, with a design life of 12 months in a one-satellite system. It was deactivated January 30, 1975, after 27.6 months. Radiometer No. 1 lost calibration March 19, 1973.

5. ITOS-E failed to achieve orbit on July 16, 1973.

6. NOAA-3 was launched November 6, 1973, with a design life of 12 months in a one-satellite system. It was deactivated on August 31, 1976, after 33.8 months. Radiometer No. 2 failed March 3, 1974.

7. NOAA-4 was launched November 15, 1974, with a design life of 12 months in a one-satellite system. It was deactivated November 18, 1978, after 49.1 months. Radiometer

No. 2 failed February 2, 1976, and radiometer No. 1 failed August 6, 1978.

8. NOAA-5 was launched July 29, 1976, with a design life of 12 months in a one-satellite system. It was deactivated July 16, 1979, after 36.6 months. Radiometer No. 1 failed February 24, 1978, and radiometer No. 2 failed March 16, 1978.

9. TIROS-N (NASA funded) was launched October 13, 1978, into the afternoon orbit in a two-satellite system, with a design life of 14 months. It lost attitude control February 27, 1981, after 29.5 months.

10. NOAA-6 was the first of the new series procured by NOAA. It was launched June 27, 1979, into the morning orbit in a two-satellite system, with a design life of 24 months. It is still used operationally (as of March 20, 1985) after 68 months, even though the HIRS-2 sounding unit failed September 19, 1983, after providing 51 months of useful data. This satellite was placed in a standby status for several months.

11. NOAA-B failed to achieve orbit on May 29, 1980.

12. NOAA-7 was launched June 23, 1981, into the afternoon orbit in a two-satellite system, with a design life of 24 months. It was placed in standby status on February 27, 1985, after providing 44 months of service, and is available for backup.

13. NOAA-8 was launched March 28, 1983, into the morning orbit in a two-satellite system, with a design life of 24 months. It lost attitude control July 1, 1984, after 15 months.

After this analysis of the POES management was initiated, NOAA-9 was launched on December 12, 1984, into the afternoon orbit. It was declared operational on February 18, 1985, and is the prime satellite as this is written. It was not included in the analysis because it was declared operational after the 15th year of the historical period.

If the experiences of the POES system to date were applied to the analysis of the long-term POES as conventionally planned, it is likely that:

- in a series of 11 or more satellites needed for a nominal one-satellite system, shown in Figure I-3, there will be at least two launch failures and two premature failures on orbit; and

- in a series of 16 or more satellites needed for a nominal two-satellite system, shown in Figure I-1, there will be at least three launch failures and three premature failures.

In the simplest of scenarios, NOAA could manage the system as shown in the nominal planning charts. If the "most likely" failures were to occur, and replacement satellites were not called up and launched, the long-term performance of the POES would be as shown in Figures II-1 and II-2. Data gaps would occur in both systems as shown in the figures. In the one-satellite system, there would be no satellite data 30 percent of the time. In the two-satellite system, there would be no satellite data 13 percent of the time and data would be available only from the less preferred AM satellite 20 percent of the time.

These are but examples of events that could occur over the next 15 years of POES operation. This study attempts to apply the lessons of the past to the plans for the future.

C. Scope and Assumptions

In this analysis, satellites presumed to be orbited from now to the year 2000 would be essentially the same as those now in use. This does not preclude changes in sensor systems, or incremental modifications to the sensor complement or the spacecraft itself, provided these changes do not reduce expected on-orbit lifetimes. In some tests, satellites of a new design were presumed to enter service early in the 15-year planning period.

Satellites of a radically new design, such as those that will be feasible when the Space Station becomes operational, are excluded from this study. Astronaut servicing, repair, or replacement of components will radically change launch schedules and on-orbit lifetimes. Totally new systems management concepts will be needed to ensure optimum POES management in a system based on the Space Station and its capabilities.

All previous POES satellites were launched using expendable launch vehicles. Although this choice of launch vehicles is presumed in this study, it is not a critical element in the analysis of system management considerations. Satellites launched later in this 15-year period can be launched just as well from the Shuttle, and the conclusions reached in this analysis will not be altered provided that:

- requirements for fixed launch schedules and call-ups for replacement launches can be met, and

Figure II-1

Probable one-satellite system scenario with a 24-month design life and 18-month launch interval if two launch failures and two premature failures were not replaced

```
--------------------------------------------------------------------------------------------------------------
MONTHS    10         20         30         40         50         60         70         80         90        100        110
          !          !          !          !          !          !          !          !          !          !          !
1                       24
Sssssssssssssssssssssss
                 18
2            (2) 0
                                   36                      60
3                              (3) Sssssssssssssssssssssssss
                                                     54
4                                                (4) 0
                                                                       72                      96
5                                                                  (5) Sssssssssssssssssssssssss
                                                                                         90          102
6                                                                                    (6) Sssssssssssss]
                                                                                                         108(110)
7                                                                                                      (7) Sss
--------------------------------------------------------------------------------------------------------------
MONTHS             110       120       130       140       150       160       170       180
                   !         !         !         !         !         !         !         !
                                        132
7 continued        sssssssssssssssssssssss
                                  126         138
8                              (8) Sssssssssss]
                                                    144
9                                                (9) 0
                                                                      162              (180)
10                                                               (10) Ssssssssssssssssss 186
                                                                                        180
11                                                                                 (11) S  204
--------------------------------------------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
O = Launch failure
] = Premature failure 12 months before the design lifetime

Figure II-2

Probable two-satellite system scenario with a 24-month design life and 12-month launch interval if three launch failures and three premature failures were not replaced

```
---------------------------------------------------------------------------------------
MONTHS  10      20      30      40      50      60      70      80      90      100     110
         |       |       |       |       |       |       |       |       |       |       |
1                  24
Pppppppppppppppppppppppp
              12   24
2         (2) Aaaaaaaaaaaa]
                   24
3               (3) 0
                             36                   60
4                      (4) Pppppppppppppppppppppppp
                                        48
5                                   (5) 0
                                                  60                  84
6                                             (6) Pppppppppppppppppppppppp
                                                            72                  96
7                                                       (7) Aaaaaaaaaaaaaaaaaaaaaaaa
                                                                      84        96
8                                                                 (8) Pppppppppppp]
                                                                                96        (110)
9                                                                           (9) Aaaaaaaaaaaaaa
                                                                                          108(110)
10                                                                                   (10) Ppp
---------------------------------------------------------------------------------------
MONTHS              110     120     130     140     150     160     170     180
                     |       |       |       |       |       |       |       |
                             120
9 continued         aaaaaaaaaa
                                     132
10 continued        pppppppppppppppppppppppp
                             120               144
11                      (11) Aaaaaaaaaaaaaaaaaaaaaaaa
                                     132
12                              (12) 0
                                               144        158
13                                        (13) Pppppppppppppp]
                                                         156               180
14                                                  (14) Aaaaaaaaaaaaaaaaaaaaaaaa
                                                                   168     (180)
15                                                            (15) Pppppppppppp  192
                                                                           180
16                                                                    (16) A  204
---------------------------------------------------------------------------------------
```

LEGEND
P = Launch of a satellite into the afternoon orbit
A = Launch of a satellite into the morning orbit
0 = Launch failure
] = Failure 12 months before the design lifetime

- Shuttle launch costs (including the costs to make the satellites Shuttle-compatible) do not significantly distort the analyses of total systems costs.

New or improved services from sensor systems other than those now in use are beyond the scope of this study, but the results of modest improvements in the reliability of existing satellite sensors or spacecraft components are explored as a part of the evaluation of the management options for a long-term POES system. No attempt is made in this study to define how improvements in reliability might be achieved.

D. Methodology

The method used in this study was to model the 15-year POES system under a variety of assumptions about satellite on-orbit lifetimes, fixed launch schedules, and possible intervals to call-up launches of replacement satellites after premature or launch failures. System performance statistics and long-term costs were derived or calculated from these models (called scenarios). Models and derived statistics were developed for both the one-satellite system and the two-satellite system, and every effort was made to ensure that all assumptions were applied uniformly to both systems.

We found no elegant way to provide an ab initio probability analysis based on present designs of sensors, spacecraft, and launch vehicles, so we used "brute force" and analyzed over 120 scenarios to derive the principles, then applied these to "realistic" scenarios.

By using the more than 120 different combinations of management principles and sequences of satellite failures, the management principles that best meet the POES service goals at the most reasonable cost were determined. The number and timing of launch failures was varied within reasonable bounds, based on past experience. The timing of on-orbit failures of satellites was varied using past experience as a guide. Finally, satellite on-orbit lifetimes were varied within a range based on past experience.

Different management approaches were applied to these results. The baseline used in the analysis was the launch of satellites on the schedule assumed in the budget planning scenarios (Figures I-1 and I-3). To this were added call-up capabilities, with different assumed delays ranging from 4 to 9 months. The timing of the nominal launch schedule was extended by a few months in some tests. In some tests, methods were developed to take advantage of extended on-orbit lifetimes when they occur. Some scenarios were modeled to take advantage of possible early warnings of imminent on-orbit failure.

METHODOLOGY

ANALYZED 121 SCENARIOS

VARIED

- FAILURES AND SEQUENCES OF FAILURES
- EXTENDED LIFETIMES AND SEQUENCES OF THESE
- DESIGN LIFETIME (24, 28, AND 32 MONTHS)
- LAUNCH SCHEDULES
  - -- 12, 14, AND 16 MONTHS FOR TWO-SATELLITE SYSTEM
  - -- 18, 20, AND 22 MONTHS FOR ONE-SATELLITE SYSTEM
- CALL-UP SCHEDULE (4 MONTHS, 6 MONTHS, 9 MONTHS OR NONE)
- WHETHER WE TOOK CREDIT FOR EXTENDED LIFE (YES OR NO)
- WHETHER THERE WERE A FEW MONTHS OF WARNING OF IMMINENT FAILURE (YES OR NO)

MEASURED

- SERVICE (IN PERCENTAGE OF TIME)
  - -- AT LEAST ONE SATELLITE
  - -- IMPROVED WITH DUAL SATELLITES (TWO-SATELLITE SYSTEM ONLY)
  - -- DEGRADED WITH AM SATELLITE ONLY (TWO-SATELLITE SYSTEM ONLY)
- COSTS (DOMINATED BY THE NUMBER OF SATELLITES NEEDED, BUT INCLUDING LAUNCH USER CHARGES AND OPERATIONS COSTS)

USED NOMINAL PLANNING SCENARIOS AS A BASELINE

- 18-MONTH LAUNCH CENTERS AND NO FAILURES FOR ONE-SATELLITE SYSTEM
- 12-MONTH LAUNCH CENTERS, NO FAILURES, AND NO EXTENDED LIFE FOR TWO-SATELLITE SYSTEM

Some illustrative examples of the scenarios are shown in Figures II-3 through II-6 (see pages 25-28). These figures show the key differences found in testing the management strategies. The summary of some of these tests, shown in Table I-3, indicates the result of progressively varying some of the management principles and failure parameters. Adding a call-up capability significantly increases the number of satellites needed in either system configuration, but dramatically improves the services. Taking advantage of extended lifetimes substantially reduces the number of satellites needed in the two-satellite system without significantly degrading the service.

Volume 2 of this report includes the complete step-by-step description of this methodology, including detailed analyses of the performance and costs of both systems under each set of assumptions. The appendices in Volume 3 provide the complete computer output of the modeled scenarios and their costs.

Figure II-3

**Probable one-satellite system scenario
with a 24-month design life and 18-month launch interval
if two launch failures and two premature failures
were replaced 4 months after failures**

```
-----------------------------------------------------------------------------------------------
MONTHS  10       20       30       40       50       60       70       80       90      100      110
         :        :        :        :        :        :        :        :        :        :        :
1                    24
Sssssssssssssssssssssss
               18
2           (2) 0
                   22                      46
3             (3) Sssssssssssssssssssssssss
                                    40
4                              (4) 0
                                       44                      68
5                                  (5) Ssssssssssssssssssssssss
                                                         62                      86
6                                                    (6) Ssssssssssssssssssssssss
                                                                        80                      104
7                                                                   (7) Ssssssssssssssssssssssss
                                                                                         98          110
8                                                                                     (8) Sssssssssssss]
-----------------------------------------------------------------------------------------------
MONTHS             110      120      130      140      150      160      170      180
                    :        :        :        :        :        :        :        :
                       114                      138
9                  (9) Sssssssssssssssssssssssss
                                       132          144
10                                (10) Sssssssssssss]
                                                           148                    172
11                                                    (11) Sssssssssssssssssssssssss
                                                                        166           (180)
12                                                                 (12) Sssssssssssssss  190
-----------------------------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
O = Launch failure
] = Premature failure 12 months before the design lifetime

Figure II-4

Probable one-satellite system scenario with a 24-month design life and 18-month launch interval if three launch failures and three premature failures were replaced 4 months after failures

```
--------------------------------------------------------------------------------------------------------------
MONTHS   10        20        30        40        50        60        70        80        90        100       110
          ¦         ¦         ¦         ¦         ¦         ¦         ¦         ¦         ¦         ¦         ¦
1                      24
Pppppppppppppppppppppppp
           12          24
2      (2) Aaaaaaaaaaaa]
                       24
3                  (3) 0
                           28                      52
4                      (4) Ppppppppppppppppppppppppp
                                       40
5                                  (5) 0
                                           44                      68
6                                      (6) Ppppppppppppppppppppppppp
                                                       56                      80
7                                                  (7) Aaaaaaaaaaaaaaaaaaaaaaaaa
                                                                   68          80
8                                                              (8) Pppppppppppp]
                                                                               80                      104
9                                                                          (9) Aaaaaaaaaaaaaaaaaaaaaaaaa
                                                                                           92              (110)
10                                                                                    (10) Ppppppppppppppppppp
                                                                                                       104 (110)
11                                                                                                (11) Aaaaaa
--------------------------------------------------------------------------------------------------------------
MONTHS             110       120       130       140       150       160       170       180
                    ¦         ¦         ¦         ¦         ¦         ¦         ¦         ¦
                        116
10 continued       ppppppp
                        116
11 continued       aaaaaa]
                        116
12                  (12) 0
                            120                     144
13                      (13) Ppppppppppppppppppppppppp
                                        132                     156
14                                 (14) Aaaaaaaaaaaaaaaaaaaaaaaaa
                                                    144                     168
15                                             (15) Ppppppppppppppppppppppppp
                                                                156                     180
16                                                         (16) Aaaaaaaaaaaaaaaaaaaaaaaaa
                                                                            168       (180)
17                                                                     (17) Pppppppppppp ] 192
                                                                                        180
18                                                                                 (18) A ] 204
--------------------------------------------------------------------------------------------------------------
```

LEGEND
- P = Launch of a satellite into the afternoon orbit
- A = Launch of a satellite into the morning orbit
- O = Launch failure
-] = Failure 12 months before the design lifetime

Figure II-5

Probable one-satellite extended-life scenario with a 28-month design life and 20-month launch interval with launch or premature failures replaced in 4 months

```
-------------------------------------------------------------------------------------------
MONTHS   10        20        30        40        50        60        70        80        90       100       110
         :         :         :         :         :         :         :         :         :         :         :
1                          28
Ssssssssssssssssssssssssssss
                   20
2              (2) 0
                       24                            52
3                  (3) Sssssssssssssssssssssssssssss
                                       44
4                                  (4) 0
                                           48                            76
5                                      (5) Sssssssssssssssssssssssssssss
                                                               68                            96
6                                                          (6) Sssssssssssssssssssssssssssss
                                                                                   88        100 104
7                                                                              (7) Sssssssssssslsssl
                                                                                                 104  (110)
8                                                                                            (8) Sssssss
-------------------------------------------------------------------------------------------
MONTHS             110       120       130       140       150       160       170       180
                   :         :         :         :         :         :         :         :
                                         132
8 continued        sssssssssssssssssssssss
                             124         136 140
9                        (9) Sssssssssssslsssl
                                             140                           168
10                                      (10) Sssssssssssssssssssssssssssss
                                                           160                 (180)
11                                                    (11) Sssssssssssssssssssss  188
                                                                                 180
12                                                                          (11) S  208
-------------------------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
0 = Launch failure

Figure II-6

Probable two-satellite extended-life scenario if satellites follow the exact POES history and replacements were launched 4 months after launch failures or failures on-orbit

```
--------------------------------------------------------------------------------------------
MONTHS   10        20        30        40        50        60        70        80        90        100       110
         |         |         |         |         |         |         |         |         |         |         |
1                           29
Pppppppppppppppppppppppppppp]   (29 months)
           12                                      53
2      (2) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa]   (41 months)
                                33
3                       (3)  0
                                    37                                      74
4                               (4) Ppppppppppppppppppppppppppppppppppppp]   (37 months)
                                                       57             72
5                                                  (5) Aaaaaaaaaaaaaaa]   (15 months)
                                                                         76                         105
6                                                                    (6) Ppppppppppppppppppppppppppppp]
                                                                                                (29 months)
                                                                             80                         (110)
7                                                                        (7) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
                                                                                                      109
8                                                                                                  (8) 0
--------------------------------------------------------------------------------------------
MONTHS             110       120       130       140       150       160       170       180
                   |         |         |         |         |         |         |         |
                              121
7 continued        aaaaaaaaaaa]  (41 months)
                     113                                   150
9                  (9) Ppppppppppppppppppppppppppppppppppppp]  (37 months)
                                   125            140
10                        (10) Aaaaaaaaaaaaaaa]  (15 months)
                                                   144                           173
11                                            (11) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaa]  (29 months)
                                                            154                      (180)
12                                                     (12) Pppppppppppppppppppppppppp   ] 195  (41 months)
                                                                                   177
13                                                                            (13) 0
--------------------------------------------------------------------------------------------
```

LEGEND

P = Launch of a satellite into the afternoon orbit
A = Launch of a satellite into the morning orbit
O = Launch failure
] = Satellite failure (without early telemetry indications)

III. ANALYSIS

A. Background

The optimum management approach for either POES system should provide fully reliable services at all times, perhaps supplying some additional service above the minimally acceptable level, and should keep the costs to the lowest possible level. This service should be provided under all conditions, no matter what failures of satellites or launch vehicles occur.

This study included an extensive analysis of over 120 different possible scenarios designed to understand the impact of launch failures and short satellite lifetimes on services to the users. The key factors examined were months of prime mission data (soundings and images) from zero, one, or two satellites on orbit over a 15-year period, and the costs over the same period.

The planning for the present two-satellite system is based on assumed satellite lifetimes of 24 months on orbit. The fixed launch interval is 12 months. Satellites that fail at launch or before they reach the end of their design lifetimes on orbit are expected to be replaced in 4 months. In this study, this POES system plan is called the two-satellite baseline system.

The one-satellite baseline system assumes a 24-month lifetime, with launches on a fixed schedule of 18 months. Replacement launch after failure is expected in 4 months.

Probabilities of future satellite failures were analyzed, based on the history of the POES system since 1970 and, more particularly, on events that have occurred since the first satellite of the present design was launched in 1978.

It is likely that over the next 15 years, the two-satellite baseline system will suffer either three or four launch failures, combined with three premature failures on orbit. Since fewer satellites are needed in a one-satellite system, there probably will be either two or three launch failures, combined with two premature on-orbit failures.

One goal of this study of the management of the POES system was to determine how well the one-satellite or the two-satellite systems would meet the needs of the National Weather Service and the user community at large if these combinations of satellite failures occur over the next 15 years. Effects on user services and long-term costs were examined if the satellite design lifetimes, launch schedules, and call-up

schedules were longer than those in the baseline systems.

Another goal in these analyses was to identify the worst probable sequences of events (launch failures and failures on orbit before the end of the design lifetimes) from the user's perspective, and to devise system management approaches that would provide the best services to the users at the lowest long-term cost, in spite of these worst cases.

One bit of conventional wisdom was demonstrated in the results from all the scenarios. A satellite must be available on the ground to launch as a replacement for a failed on-orbit satellite or one that fails at launch. If the "pipeline" is not full for either system configuration, none of the more difficult scenarios can be accommodated without substantial loss in service. Therefore, this has been taken as the first management principle for any future management strategy for either the one-satellite or two-satellite system.

B. Analysis of Alternatives for Management of a One-Satellite System

Starting with the nominal baseline used in planning the budget, a number of variations in the management strategies were tried and tested against various combinations of satellite lifetimes and launch failures.

The conventional budget planning for the one-satellite system does not specifically include provisions to replace satellites that fail at launch or prematurely on orbit. The history of the POES program since 1970 leads to the conclusion that some failures are inevitable during the next 15 years, however.

Without replacements in the one-satellite baseline system, there probably will be data gaps up to 30 percent of the time over the next 15 years. Individual periods when no satellite data will be available are likely to be 6 to 24 months long. This POES management plan cannot meet the needs of the National Weather Service and other users.

Launching replacement satellites 9 months after a launch failure in the baseline one-satellite system provides some improvement in services. A 4-month call-up after launch failures provides substantial improvement in services, and would all but eliminate data gaps caused by launch failures. However, this system management plan does not meet the POES goal of providing data from at least one satellite at all times, because there would be no satellite data 6 to 15 percent of the time. The cost of these improvements in services over those from the baseline plan are 15 percent higher if there were 9-month call-up, or 22 percent higher with 4-month call-up.

Because satellites of the current design have lasted an average of 30 months, rather than the nominal 24-month design life, there is little risk in assuming a future design life of 28 months (slightly under actual experience). A one-satellite POES management approach based on a design life of 28 months and a launch schedule of 22 months was tested. This plan was found to be more desirable than the baseline system, because it provides about the same level of services as the baseline system with replacements. The long-term cost is about 17 percent less than that of the baseline. This version of a 28-month design life system still does not meet the POES management goal of providing data from at least one satellite at all times, because there would be no satellite data 6 to 16 percent of the time.

Changing the launch interval in this 28-month life system from 22 to 20 months marginally improves services. Periods of a year or more without satellite data could still occur in the worst case. The 11 percent increase in cost over the system with the 22-month launch interval is not justified by the modest improvements in services.

Next, system performance was tested if replacements were launched after premature failures on orbit, as well as after launch failures. It is a near certainty that managing the one-satellite POES system with a 28-month design life, 20-month launch interval, and a 4-month call-up after all failures would result in meeting the POES management goal of providing data from at least one satellite 100 percent of the time over the 15 years of this analysis.

The 15-year cost of such a 28-month one-satellite management plan would probably be the same as, or perhaps slightly lower than, the cost of the one-satellite system normally considered in budget planning with no replacements after failures.

While no such capability now exists, a one-satellite system with a 32-month extended life was modeled to see if it was a suitable plan for the future. It was found that, if improvements in the reliability of satellite systems were made, this system plan probably would meet the basic needs of the National Weather Service for data from one satellite at all times. It would cost about 10 percent less than the acceptable POES management alternative based on a 28-month lifetime. Estimated savings in long-term system costs <u>do not consider</u> the development costs of making the improvements in reliability needed to plan on a 32-month system.

A one-satellite management plan was examined based on anticipating that the recent history of satellite performance would be repeated for the one-satellite system. It was found that this one-satellite management plan system does not meet

the needs of the National Weather Service because, over the long term, data voids would occur between 2 and 16 percent of the time. Periods without satellite data of 4 to 8 months would not be unusual.

If satellite and launch failures follow the pattern of the recent past, the only one-satellite management plan that appears from the modeling to be almost certain to meet the minimum POES management goal 100 percent of the time is the system with an assumed 28-month design life, 20-month launch interval, and replacements launched in 4 months following all failures. It requires the launch of 12 satellites during the next 15 years.

C. Best Management Plans for a One-Satellite System

Five fundamental principles derived from the analysis of the management of a one-satellite system are:

- procure enough satellites on a schedule such that one is always ready to replace a satellite that fails on orbit or at launch;
- arrange for a 4-month call-up capability;
- take advantage of extended lifetimes by planning an average lifetime like that of recent experience, namely, 28 months;
- launch at intervals shorter than the expected lifetime by more than the call-up period (namely, 20-month intervals) to permit replacing satellites that fail at launch; and
- launch before the 20-month nominal schedule if there are indications of imminent on-orbit failure.

If there are indications of an imminent failure 4 months or more before an on-orbit satellite ceases to provide images and soundings, such a POES management plan for a one-satellite system will assure that data from at least one satellite will be available at all times. If these early indications are absent, periods of up to 4 months when there is no satellite data are possible. Data voids would occur between 4 and 7 percent of the time over the next 15 years. The exception to these projections of service continuity occurs if a premature failure on orbit is followed immediately by a launch failure, in which case a data gap of up to 8 months would result.

The cost of this POES one-satellite management plan would range between 10 percent below and 5 percent above the cost of

the one-satellite baseline system, depending on whether there are two or three launch failures over the next 15 years.

D. Analysis of Alternatives for Management of a Two-Satellite System

The baseline two-satellite POES management plan, if replacement satellites were not launched after any failures, would probably provide data services from at least one satellite 92 percent of the time over the next 15 years. Periods of 12 months or more without data could occur if a launch failure immediately followed a premature failure on orbit. Only data from satellites in the morning orbit would be available 20 percent of the time, for periods as long as a year. The needs of those users who require services from a dual satellite system would be met 38 percent of the time.

This two-satellite baseline plan without replacements would cost 45 percent more than the one-satellite baseline plan, or 38 percent more than the only one-satellite management plan found that would probably provide data services from one satellite 100 percent of the time over the next 15 years.

Instituting a 6-month call-up to replace satellites that fail to achieve orbit reduces by about one-half the periods when no satellite data would be available. The longest individual periods without data probably decrease from 12 to 6 months. Periods with dual satellite services increase to 47 or 57 percent of the time, depending on whether there were three or four launch failures. Replacing satellites that do not achieve orbit increases long-term system costs by 5 to 10 percent.

A 4-month replacement of satellites that fail on launch results in data gaps 4 percent of the time over 15 years. If call-up schedules were 6 months, data voids would occur 13 percent of the time. Neither the 6- nor 4-month call-ups in the 24-month baseline system change the amount of time (7 percent) when data from only satellites in the morning orbit would be available. The 4-month call-up provides a 16 percent increase in the long-term availability of dual satellite data services. The system cost with a 4-month call-up is 11 percent higher than that of the baseline system without replacement.

Because satellites of the current design have lived an average of 30 months, rather than the nominal 24-month design life, there is little risk in assuming a design life of 28 months (just less than actual experiences) in the future. If the baseline system's design life were changed to 28 months, and its launch interval to 16 months, the system cost is 20 to 24

percent less than that of the baseline system. Some system performances are degraded significantly, however. Periods with data from only satellites in the AM orbit increase from 7 percent in the 24-month system to 7 to 17 percent in the 28-month system, depending on the number of assumed launch failures. Dual data services would be available about twice as often from the 24-month design life system (40 to 60 percent of the time) than from the 28-month life system (27 to 38 percent of the time). This does not meet the minimum POES service requirements.

Both the 24- and 28-month design life systems, with launch intervals of 12 and 16 months, respectively, would provide data from at least one satellite between 93 and 96 percent of the time over the next 15 years. Individual periods of 12 months without satellite data could occur, if replacements are launched 6 months after a launch failure, or up to 4 months if replacements were launched on a 4-month schedule. A premature failure immediately followed by a launch failure would increase the length of these individual data voids by 6 to 12 months.

Reducing the launch interval in the 28-month system from 16 to 14 months significantly improves services. Periods without data, which would have occurred 4 to 7 percent of the time, were reduced to 2 to 4 percent. The longest period without satellite data (6 months) with the 16-month launch schedule probably would be reduced to 2 months. There is little impact on periods when data from only satellites in the morning orbit would be available. Periods with dual data services were increased from 27 to 38 percent of the time to 40 to 54 percent, when using the 14-month launch schedule. Individual periods of dual data services probably would increase from 12 to 30 months.

The 28-month two-satellite system with a 14-month launch interval does as well as or better than the 24-month system in avoiding data gaps and reducing periods when degraded data are available. Dual data services probably would be available about 6 percent more often from the 24-month system.

The two-satellite system with a design life of 28 months and a 14-month launch interval costs 6 to 12 percent more than if the launch interval is 16 months. Long-term costs are 13 to 15 percent less than those of the two-satellite baseline system with replacements called up only after launch failures.

If all satellites that fail before their expected lifetimes, rather than just those satellites that fail at launch, were replaced in 4 months in the two-satellite baseline system, the system probably would provide satellite data services 96 percent of the time. All periods with data from only

satellites in the AM orbit would be eliminated. Concurrent services from two satellites would be available 60 to 80 percent of the time, depending on the number of assumed launch failures. System costs are about 10 percent higher than if replacements were launched only after launch failures.

The POES management plan for the two-satellite system with a design life of 28 months, a 14-month launch interval, and a 4-month call-up to replace all satellites that fail, probably would result in dual data services being available 70 to 74 percent of the time. All periods with data from only AM satellites would be eliminated. Long-term costs are 5 to 10 percent higher than those of the baseline two-satellite system, and 17 to 22 percent higher than if only launch failures were replaced in the 28-month system. This system management plan probably would result in data from at least one satellite being available up to 98 percent of the time.

Unlike the one-satellite system, the two-satellite POES can be managed to take advantage of long on-orbit lifetimes when they occur, while protecting satellite services to the users when on-orbit lifetimes are short. To do this, satellites are launched only following launch failures or when satellites in orbit fail. For this planning concept to be effective, replacements must be launched in 4 months.

The two-satellite system managed to take advantage of extended lifetimes of the satellites, with or without early indications of on-orbit failure, and probably would provide data services from at least one satellite greater than 99 percent of the time. Images, soundings, and other services from satellites in both the afternoon and morning orbits would probably be available about 80 percent of the time over the next 15 years. This is excellent service.

Services to the users would be better if there were early indications that on-orbit satellites were about to fail. The lack of these early indications would not preclude high quality service, however.

If the future two-satellite system follows the recent history of the POES in this form of extended-life management, 12 satellites would be required over the next 15 years. It is possible, though unlikely, that this extended-life management plan could require the launch of 13 satellites.

E. Best Management Plans for a Two-Satellite System

A two-satellite management plan with a 28-month design life, a launch interval of 14 months, and a 4-month call-up meets the

minimum POES management goal 98 percent of the time. Services from only satellites in the AM orbit would be available up to 3 percent of the time, and from satellites in both the AM and PM orbits about 70 percent of the time over the next 15 years. Costs of this system would be 5 to 11 percent more than those of the baseline two-satellite system.

Adding replacements for satellites that fail at launch or prematurely on orbit in the baseline 24-month system makes available satellite data services 96 percent of the time. Dual satellite data services probably would be available about 80 percent of the time over the next 15 years. Costs are 21 percent higher than the baseline system without replacements.

If only launch failures are replaced in 4 months in the 24-month baseline system, there would be no satellite data 4 percent of the time. Only degraded data would be available 7 percent of the planning period. Between 50 and 60 percent of the time, services from dual satellites would be available. Costs are 11 percent more than those of the baseline system without replacements, and 9 percent less than if premature failures were also replaced.

The optimum management plan for the two-satellite POES system appears to be one designed to take advantage of long on-orbit lifetimes when they occur, while protecting services to the users by promptly launching replacements when lifetimes are short. Satellites are launched in 4 months only upon the failure of a satellite on orbit, or after any launch failure. Four fundamental principles derived from the analysis of the management of the two-satellite system are:

- procure enough satellites on a schedule such that one is always ready to replace a satellite that fails on orbit or at launch;

- arrange for a 4-month call-up capability (if the call-up period is greater than 4 months, services can be degraded significantly);

- take advantage of extended lifetimes by delaying the launch of a satellite until there is a failure; and

- launch a replacement satellite within 4 months of an indication that an on-orbit failure is imminent.

Extended-life systems managed in this way probably would meet the minimum POES management goal of providing data from at least one satellite at all times. Services from two operational satellites on orbit would be available 70 to 80 percent of the time over the next 15 years, depending on the

number of launch failures that occur and on the presence or absence of early indications of impending on-orbit failures. In addition, periods with only data from satellites in the morning orbit would occur no more than 2 to 11 percent of the time over the next 15 years.

The cost of this extended-life POES management plan is 68 to 90 percent of that of the baseline two-satellite system with a 24-month life without replacement launches.

F. Discussion of the Analysis

Neither the future one-satellite nor two-satellite POES system is likely to behave precisely as modeled in this study. Therefore, projections of detailed service levels from the various management plans must be considered as approximations, rather than finite predictions, of exactly what will happen at all times in the next 15 years. Thus, any scenarios that would provide data from one satellite at least 95 percent of the time are probably about equal in their ability to meet the minimum POES management goal all of the time.

G. Call-Up Schedule

The analysis shows that the call-up schedules should be shortened as much as possible. All of the tests showed better service with shortened intervals. Four months is a reasonable and achievable time, based on past experience. It is the call-up period that has been the goal in the management of the past POES system.

In both the one-satellite and two-satellite systems, the 4-month schedule for call-ups (rather than a 9-month schedule for one-satellite systems or a 6-month schedule for two-satellite systems used in the testing) reduces periods when there would be no satellite data. On average, periods without data would be reduced by 8 months.

In some one-satellite management plans, the 4-month call-up eliminates all data gaps, but the 9-month call-up leaves data voids 6 to 11 percent of the time. In the two-satellite system, periods with dual data services increase by 3 to 12 percent.

Shorter call-up schedules could increase the long-term cost by 8 percent in the one-satellite system and by about 5 percent in the two-satellite system, because an additional satellite is needed in some, but not all, scenarios.

H. Extending On-Orbit Lifetimes

Management of the POES system in either configuration should take advantage of possible extended lifetimes of the satellites. Both systems should benefit from the fact that the actual performance of satellites of the present design has exceeded the nominal design life, in some cases providing services for periods twice as long as the design life or longer.

Plans using satellites of a proven design can be based on at least an average 28-month lifetime, based on recent experience. The one-satellite configuration should use this estimate of average lifetimes in planning launch schedules, allowing for time to call up a replacement in the event of a launch failure. The two-satellite configuration can actually launch satellites only after failures, thus taking full advantage of long on-orbit lifetimes when they occur. A 4-month call-up is essential if these POES systems are to meet the minimum service goals.

If the on-orbit reliability were improved enough to permit POES program managers to depend on satellite lifetimes being extended by 4 months, data services would not be degraded. Costs to build and launch satellites over the next 15 years might be reduced by up to $100 million. In this analysis, no attempt was made to determine the cost of making the improvements needed in sensor systems or spacecraft components to assure that satellites would consistently last 4 months longer.

I. Optimum System Management Strategies

The nominal budget planning strategy cannot meet the minimum POES service goals for either the one-satellite or the two-satellite systems. Operating a POES system in such a manner is not a wise use of funds invested in the procurement and launching of satellites.

Introducing the ability to replace satellites after launch failures or premature failures on orbit significantly improves the data service statistics. This is true in both a one-satellite and a two-satellite system. Such a management scheme improves the ability of both systems to meet management goals. However, in both systems the costs are increased over those of the baseline system.

The most cost-effective system management approach is one that takes advantage of extended on-orbit lifetimes, while at the same time taking all possible and reasonable steps to maintain reliable data services when launch failures and premature

on-orbit failures occur. Such scenarios provide assurance of data virtually 100 percent of the time from either system, given the statistics on POES failures that have been experienced in the past.

For the two-satellite system, the optimum management approach would wait to launch a satellite until an on-orbit satellite fails. Using such an approach permits meeting the POES service goals over the next 15 years with three or four fewer satellites than are required in the baseline system (assuming a failure sequence exactly like the TIROS-N to NOAA-8 history).

For the one-satellite system, it is not possible to take advantage of extended on-orbit lifetimes in exactly the same fashion. A more feasible extended-life approach for the one-satellite system is to base system planning on 28-month on-orbit lifetimes (just less than the 30.5-month average lifetime of the last four satellites of the current design to successfully reach orbit), with launches regularly scheduled at 20-month intervals, which gives time for calling up replacements for launch failures, plus a small margin.

To be implemented, the management of the POES system in either configuration using these extended-life approaches should be based on the following operational guidelines:

- Satellites should be procured in such quantity and on such a schedule that a satellite is available for call-up in the event of a launch failure or an early on-orbit failure.

- Replacement launches should be called up 4 months after a launch failure or a premature failure on orbit (or sooner, if possible).

- For a one-satellite system, POES continuity must be provided by launching satellites on a regular schedule.

- For a two-satellite system, continuity can be provided, while taking advantage of extended on-orbit lifetimes, by replacing an on-orbit satellite only when it fails or when telemetry from the satellite indicates that a failure may be imminent.

In summary, the application of these principles gives adequate system performance at comparable long-term costs.

- For the one-satellite system, it is most likely that data from satellites in the afternoon orbit would be available 100 percent of the time. There would be no satellites in

the morning orbit. Twelve satellites would be launched in 15 years.

- In the two-satellite system, data very probably would be available 100 percent of the time. Only morning satellite data would be available 2 to 11 percent of the time, only afternoon satellite data 19 percent of the time, and dual data 70 to 90 percent of the time. Twelve or 13 satellites would be required.

The one-satellite system is more vulnerable to interruption in data services because of launch failures than the two-satellite system, since the one-satellite system depends on launches at somewhat longer intervals to provide system redundancy when taking advantage of extended lifetimes. In one two-satellite scenario with two almost simultaneous failures, there was only a 2-month period in which there would be no data. On the other hand, if a launch failure occurred following a 15-month lifetime in a one-satellite system, a gap of 4 months in data services would have occurred, even with a 4-month call-up.

No credit has been taken in this analysis for partially operational satellites, those on which the imager or sounder has failed in part, but that continue to supply partial or secondary services. These are a real bonus in a two-satellite system. They are far less of a bonus in a one-satellite system, since all satellites are in the same afternoon orbit.

Furthermore, no credit has been taken for some secondary POES service missions that are provided by having satellites in both the AM and PM orbits. Search and Rescue, direct broadcast, automatic picture transmissions to ground stations around the world, and other capabilities can continue functioning after the imager and sounder fails. Having payloads in different orbits provides better service to some users' programs, such as those requiring satellite data more frequently than twice a day. A two-satellite system managed as proposed would virtually guarantee the availability of Search and Rescue services from two satellites all the time over the next 15 years.

From the above, it can be concluded that:

- The optimum one-satellite management plan probably will meet the minimum POES management goal of providing data service from at least one satellite at all times over the next 15 years. It is the only one-satellite management plan we could devise that is almost certain to do so. This plan is based on a satellite design life of 28 months, a 20-month launch interval, and replacements launched in 4 months for all satellites that fail at

launch or before the end of their design on-orbit lifetimes.

- This one-satellite management plan has the lowest cost of any plan that would meet the minimum performance POES goal. It will require 12 satellites over the next 15 years. Its 15-year cost would be $16.82 C million, where "C" is the cost to fabricate and launch a satellite. If "C" were $75 million, the approximate cost of satellites built and launched today, the average annual cost of this optimum one-satellite management plan would be $84 million.

- The optimum management plan for the two-satellite POES system appears to be one in which satellites are launched only to replace those that fail to achieve orbit, or those on-orbit satellites that cease to provide useful images and soundings. This permits taking advantage of long on-orbit lifetimes when they occur, while protecting data services to the users when on-orbit lifetimes are short. A 4-month call-up is mandatory if this system is to perform acceptably.

- This system management plan would almost certainly provide some data services 100 percent of the time over the next 15 years. As a bonus, images, soundings, and other satellite services from fully operational satellites in both morning and afternoon orbits probably would be available 70 to 90 percent of the time.

- The optimum plan for the two-satellite system probably would require the launch of 12 satellites in the next 15 years, but a 13th could be required under some unlikely circumstances. Thus, the probable cost of this system is $17.23 C million, almost identical to that of the optimum one-satellite system. If the 13th satellite were required, the two-satellite system would cost 10 percent more.

J. Test of the Optimum System Management Plans

A test was devised to determine how well those optimum POES management plans would perform if conditions over the next 15 years were worse than those considered probable in the modeling. NOAA may soon introduce a new series of satellites of a different design, and the launch vehicle used in the future initially may be less reliable than those used in the past. In this test, the following assumptions were made:

- Satellites following the last three of the present design would be of a different design and would experience

"infant mortality" failures until malfunctioning components were improved.

- On-orbit lifetimes of the first three satellites of the new design would be shortened because of "infant mortality" problems.

- All future satellites would be launched with the TITAN II expendable launch vehicle (ELV), which initially would have less reliability than previous ELVs.

The optimum management plans for both the one-satellite and two-satellite systems handled this tough combination of failures rather well.

In the one-satellite system, there would be two periods, totalling 6 months, when there would be no satellite data. Twelve satellites would be required, the same number as in the earlier modeling of the 28-month optimum management plan.

In the two-satellite system, a 4-month gap could occur if there were no early indications of on-orbit failure, but there would be no gap if early indications were present. Data would be available from satellites in the preferred early afternoon orbit 85 to 89 percent of the time, with data from satellites in both orbits available 63 to 73 percent of the time over the 15-year period. The two-satellite system required the launch of 16 satellites. Earlier modeling of this management plan required 12 or 13 satellites.

This test confirms that the optimum management plans for the future POES system in either system configuration are sound. They will provide reasonably reliable services, even under the most extreme combination of launch and premature failures that the POES system is likely to encounter over the next 15 years.

IV. CONCLUSIONS

The preceding analysis provides the basis for establishing optimum management principles for the POES to meet the minimum service goals of the system. It also provides a basis other than the nominal budget planning scenario to project the number of satellites needed over the next 15 years to meet those service goals.

SERVICE GOALS FOR THE POES

MINIMUM SERVICE GOAL IS ONE SATELLITE AT ALL TIMES

- SOUNDINGS
- IMAGERY

SOME DEGRADATION FOR BRIEF PERIODS IS ACCEPTABLE, BUT NOT COMPLETE LOSS OF SERVICE (I.E., MORNING ORBIT ACCEPTABLE FOR BRIEF PERIODS)

ADDITIONAL DATA (I.E., FROM TWO SATELLITES IN DIFFERENT ORBITS) HAS SOME BENEFITS AND IS DESIRABLE

<u>Planning must take into account failures</u> that are likely to occur. Neither the one-satellite nor the two-satellite system depicted in the conventional budget planning scenarios will assure prime mission data for 100 percent of the time over the next 15 years. Some failures will occur. Mechanisms for recovery must be included in the system management plans.

<u>Service can be improved</u> over the conventional scenarios in a number of ways, and <u>reductions of costs</u> can be provided in several other ways.

IMPROVEMENTS OVER THE CONVENTIONAL BASELINE

THE LARGEST IMPROVEMENT IN SERVICES COMES FROM THE SHORTEST CALL-UP DELAY, IN BOTH SYSTEMS

ADDITIONAL IMPROVEMENTS IN SERVICE COME IF WE ASSUME A LONGER DESIGN LIFE (WHILE HOLDING SHORTER LAUNCH CENTERS) AND ASSUME THERE ARE EARLY INDICATIONS OF IMMINENT FAILURE

REDUCTIONS IN COST CAN BE MADE IN BOTH SYSTEMS BY ASSUMING A LONGER DESIGN LIFE

THE LARGEST REDUCTION IN COST COMES IN THE TWO-SATELLITE SYSTEM BY TAKING ADVANTAGE OF EXTENDED LIFETIMES

We offer three major conclusions:

1. <u>THE BEST MANAGEMENT PRINCIPLES FOR THE POES SYSTEM ARE LARGELY INDEPENDENT OF WHETHER THE SYSTEM IS CONFIGURED WITH ONE SATELLITE OR TWO.</u>

Application of these principles is different in two important ways. The common principles include (1) providing enough satellites so that there is always one available on the ground to be called up to replace satellites that fail at launch, (2) providing as short as possible a call-up delay (4 months), and (3) taking advantage of indications of imminent failure to call up a backup satellite.

The two systems vary in how we can take advantage of satellites that live longer than expected. In the two-satellite system, we can delay launch until failure. In the one-satellite system, we can extend the planned launch intervals to take advantage of <u>average</u> lifetime if it exceeds the design life (which it has in the recent past).

<u>Immediate replacement of failed satellites improves the expected services.</u> Calling up satellites in the event of failures in either system will not guarantee prime mission data for 100 percent of the time for the next 15 years. But call-up will improve the expected services from either system.

<u>Shortening the call-up period (the time from failure until launch) improves the service from either configuration.</u> We tested a 9-month call-up in a two-satellite configuration and a 6-month call-up in a one-satellite configuration. Periods of no data were reduced substantially using a 4-month call-up, at some additional cost (more satellites were needed).

Averaged over many scenarios, this reduction is 4 percent. In some one-satellite systems, the shorter call-up period eliminates data voids, while the 9-month call-up leaves gaps 6 to 11 percent of the time. In the two-satellite system, periods of dual data services increased by 3 to 12 percent. Long-term costs were increased by about 8 percent in the average one-satellite plan, or by about 6 percent in the average two-satellite plan, because more satellites were needed in some cases.

<u>Planning and operations should take advantage of satellites that live longer than their design life.</u> Taking advantage of extended life of satellites by delaying launches until an on-orbit satellite fails, possible in the two-satellite system, significantly reduces the cost of the system over the next 15 years. Furthermore, likely extended lifetimes improve the expectation of continuity of data 100 percent of the time in either system.

The five best operating principles for a one-satellite system are as follows:

- procure enough satellites on such a schedule that one is always ready to back up a failed satellite or a launch failure;
- arrange for a 4-month call-up capability;
- take advantage of extended lifetimes by planning on an average lifetime like that of recent experience (28 months);
- launch at regular intervals shorter than the expected lifetime by more than the call-up period (20-month intervals); and
- launch before the 20-month nominal launch period if there are indications of imminent failure.

The four best operating principles for the two-satellite system take full advantage of extended lifetimes of the satellites in orbit. They are as follows:

- procure enough satellites on such a schedule that one is always ready to back up a failed satellite or a launch failure;
- arrange for a 4-month call-up capability;
- take advantage of extended lifetimes by delaying the launch of replacement satellites until there is a failure; and
- launch earlier than planned if there are indications of imminent failure.

2. APPLYING THE BEST MANAGEMENT PRINCIPLES TO EITHER SYSTEM WILL MEET THE SERVICE GOALS FOR THE POES. BUT THE TWO-SATELLITE SYSTEM PROVIDES ADDITIONAL SERVICE AND A GREATER ROBUSTNESS.

Table IV-1 illustrates the improvements in service and reductions in cost.

The flexibility provided by the two-satellite system can provide substantially better service (additional data for the weather forecast models, plus additional service for Search and Rescue, automatic picture transmissions to remote stations, etc.) about 70 percent of the time. Enhanced service occurs during those periods when two satellites are in operation.

TABLE IV-1. IMPROVEMENTS IN SERVICE AND REDUCTIONS IN COST

	Satellites Launched	Data Service (percent of the time) No Data	AM Only	PM Only	Dual
CONVENTIONAL PLANNING SCENARIOS (NO FAILURES) -- HIGHLY IMPROBABLE					
One-Satellite System	11	0	NA	NA	NA
Two-Satellite System	16	0	0	0	100
PROBABLE SCENARIOS WITH FAILURES, NO CALL-UP REPLACEMENT LAUNCHES					
One-Satellite System	11	30	NA	NA	NA
Two-Satellite System	16	8	15	18	59
PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES 4 MONTHS AFTER A FAILURE					
One-Satellite System	13	6	NA	NA	NA
Two-Satellite System	20	4	3	19	74
PROBABLE SCENARIOS WITH REPLACEMENT LAUNCHES AND EXTENDED LIFE*					
One-Satellite System	12	0-2	NA	NA	NA
Two-Satellite System	12-13**	0-1	6	12	81

* In the one-satellite system, extended life helps service when it occurs; in the two-satellite system, we launch on failure.

** 13th launch near the end of the 15th year.

The two-satellite system would be more forgiving of premature failures and launch failures. Furthermore, it would be more robust against double failures (launch failure and short on-orbit lifetime simultaneously). This is demonstrated in many of the worst of the 121 scenarios.

3. <u>IN THE "MOST LIKELY" SCENARIO FOR THE FUTURE, THE NUMBER OF SATELLITES FOR WHICH WE SHOULD PLAN IS INDEPENDENT OF WHETHER WE HAVE A TWO-SATELLITE OR A ONE-SATELLITE SYSTEM.</u>

The one-satellite system would likely require one less (12 versus 13) satellites over a 15-year period. But the final satellite in the two-satellite system would be launched in the final months of the 15-year period.

NUMBER OF SATELLITES

	ONE SATELLITE	TWO SATELLITES
NOMINAL PLANNING SCENARIO (POOR SERVICE)	11	16
REPEAT OF HISTORY*	12	12-13
INFANT MORTALITY (ELV AND S/C)**	12***	15

* Assumes near duplication (and repeat) of the past 7 years.

** Assumes early failure of the new ELV and early failure of the new design "NOAA-NEXT."

*** Cannot recover, data gaps occur.

On the surface, this seems a startling conclusion. It is largely due to the ability of the two-satellite system to take advantage of those satellites that live longer than the design life.

Furthermore, the conclusion is consistent with the fact that over the past 15 years we have launched 13 satellites and have met our goal of no complete loss of service. The last six of these satellites of the current design have covered 7 years, with a two-satellite system. This (six satellites over 7 years) is entirely consistent with 12 or 13 satellites over 15 years.

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